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Air quality by inhalable particulate matter (PM_{10}) in five urban centers in South America

Qualidade do ar por material particulado inalável (MP_{10}) em cinco centros urbanos da América do Sul

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ABSTRACT

The present study aims to analyze the records of the inhalable particulate matter PM_{10} from 2002 to 2018 in the cities of Rio de Janeiro, São Paulo, Porto Alegre (Brazil), Montevideo (Uruguay), and Buenos Aires (Argentina), verifying if they were within the established limits and if the air quality reports, produced in each city, were contextualizing air pollution with relevant legislation and geographic factors. For this, we downloaded the air quality reports from websites of environmental agencies that, in accordance with their laws, are obligated to publish them. After reading, it was pointed out: the publication formats, if geographic factors were addressed in air quality analyses, the legal bases for the diagnosis, as well as which of them were more tolerant with air pollution, and the frequency they published their data and their justifications. Next, a comparison of the annual average and maximum in 24 hours PM_{10} records was performed. Therefore, we found that São Paulo presented the most complete document and Buenos Aires the least comprehensive. Rio de Janeiro exceeded PM10 tolerance limits several times, and Montevideo has the least polluted air quality. Only Buenos Aires did not address geographic factors as a form of analysis or suggestions. Finally, it is suggested that Porto Alegre and Buenos Aires should increase their data collection networks. The poor performance of some cities make it difficult to accomplish the task to transform them in more sustainable and healthy places.

Keywords: air pollution; particulate matter; environmental legislation.

RESUMO

O presente estudo visa observar os registros de material particulado inalável (MP_{10}) de 2002 a 2018 para as cidades do Rio de Janeiro, São Paulo, Porto Alegre, Montevidéu e Buenos Aires, verificando se eles estão em conformidade com os limites estabelecidos e se os relatórios de qualidade do ar produzidos em cada cidade estão contextualizando a poluição atmosférica com a legislação pertinente e os fatores geográficos. Para isso, foram levantados os relatórios de qualidade do ar nos *sites* dos órgãos de meio ambiente, que são obrigados a publicá-los de acordo com as leis. Após a leitura foram apontados os formatos de publicação, se foram abordados os fatores geográficos nas análises da qualidade do ar e suas bases legais para o diagnóstico, bem como qual deles é mais permissivo sobre poluição atmosférica e a frequência com que publica os dados e suas justificativas. Em seguida, também foi realizada uma comparação dos registros da média anual e máxima em 24 horas de MP_{10}. Então, concluiu-se que São Paulo apresentou o documento mais completo e Buenos Aires o menos abrangente. Com relação ao material particulado, a cidade do Rio de Janeiro ultrapassou diversas vezes os limites tolerados e Montevidéu tem o ar menos poluído. Apenas Buenos Aires não abordou os fatores geográficos como elemento de análise e sugere-se, por fim, que Porto Alegre e Buenos Aires aumentem a rede de coleta de dados. O desempenho ruim de algumas cidades deixa mais distante o cumprimento da tarefa de tornar as cidades mais sustentáveis e saudáveis.

Palavras-chave: poluição do ar; material particulado; legislação ambiental.

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Introduction

The deep process of urbanization in our history has generated major political, social, and environmental consequences with impacts on the populations's health, with a significant decline in the quality of life and a worsening of environmental health (Gouveia, 1999). Atmospheric pollution was defined according to the National Council for the Environment (CONAMA, in Portuguese) in Ordinance 003/90, which follows the World Health Organization (WHO) guidelines, such as gases and particles harmful to humans and the environment (Brazil, 1990). Particulate matter (PM) are suspended particles in the air that can be inhaled and affect human health. Only 54 countries have any strategy to mitigate this pollutant, 77 have any kind of monitoring, 92% worldwide experienced high PM in 2019, and the United Nations (UN) forecast PM will increase 50% until 2030 (WHO, 2022).

Therefore, there is a need to monitor the concentrations, because, in the long term, they will cause serious diseases and harm the environment, as already demonstrated in studies by the Pan American Health Organization and WHO (PAHO/WHO, 2018). In addition, PM is considered a carcinogen by the International Agency for Research on Cancer (IARC), associated with lung and urinary tract cancer (WHO, 2018). It is also associated with other diseases such as respiratory infections, premature births, and increased cardiorespiratory mortality (Hamra, et al., 2014; Newell, et al., 2017).

In theory, in atmospheric models, the increase in PM pollution is inversely associated with relative humidity, that is, the higher the PM emissions in the environment, the lower the relative humidity (Silva et al., 2021). Therefore, like other pollutants, this is a serious environmental and social issue, of complex solution, and several sources, such as massive industrialization (Corá et al., 2020), biomass burning, use of incinerators, and old vehicle fleets. But natural factors such as climate and relief can also influence the concentration or dispersion of pollutants (Park, 1987) and therefore must be included in the weighting of air quality reports.

Since the events of pollutant accumulation in the atmosphere depend on the emitting sources and specific atmospheric conditions, monitoring the concentration of atmospheric pollution is paramount. As an example, in the event of the truck drivers' strike in 2018, the suppression of these vehicles caused a drop in PM_{10} in Limeira and Campinas/SP (Nogarotto et al., 2022).

One way of disclosing the behavior of atmospheric pollution over time is the formulation of air quality reports, the result of constant monitoring, which must be published regularly by cities after signing the Mercosur treaty (Mercosul, 2001).

The approach to environmental law and collective health is essential to understand the actions of air quality control. Environmental law focuses on regulating human activities that pollute the environment to preserve health and well-being (Souza et al., 2015), while collective health emphasizes the impact of a healthy environment on individuals' quality of life. (Minayo, 2014). This knowledge can be applied through an interdisciplinary deepening in order to better understand the evolution of atmospheric pollution in cities such as Rio de Janeiro, São Paulo, Porto Alegre (Brazil), Montevideo (Uruguay), and Buenos Aires (Argentina).

Because atmospheric pollutants cause harm to health, limits must be established for the concentration of these contaminants. In Brazil, Uruguay, and Argentina the regulation of air pollutants was inspired by United States Environmental Protection Agency (US EPA) legislation, which began in the 1970s and underwent updates over time. In general, these limits are very far from WHO recommendations. However, during this research, there were new laws updating the limits, as São Paulo in 2013, and Montevideo in 2016, trying to transition to more adequate levels and meet the WHO recommended levels. So, the air pollution problem involves a lot of other knowledge areas such as engineering, law, and geography, as well as our day-by-day in an interdisciplinary way.

Thus, to better understand the most favorable conditions for PM_{10} concentrations in these cities, we dialogued with the geography present in the air quality reports of these cities, which served as a basis for understanding the application of legislation, their adequacy to space, and the control of environmental impacts, managing to deal with different scales of work and better interconnecting subjects of objective and subjective essence.

As the subject has very large links with many areas, we connected geography, laws and collective health trying to enhance what we know about it. Thus, the main objective of the study was to analyze the PM_{10} records in the air quality reports from 2002 to 2018 for Rio de Janeiro, São Paulo, Porto Alegre, Montevideo and Buenos Aires, verifying whether they were under the established limits, and if these reports were contextualizing air pollution with the relevant legislation and geographic factors. Because if we assess this link, maybe the stakeholders can solve this problem properly, in an interdisciplinary way, consulting in a serious manner, the population and experts.

Methodology

The present study refers to the type of document analysis where air quality reports, that serve as the basis for the research, are available on the websites of environmental agencies, such as: the State Institute of the Environment (INEA) of Rio de Janeiro, Environmental Company of State of São Paulo (CETESB), State Environmental Protection Foundation Henrique Luis Roessler (FEPAM), and Municipal Secretariat of Environment, Urbanism and Sustainability (SMAMUS) of Porto Alegre. Additionally, data from the Air Quality Laboratory in Montevideo and the General Directory of Environmental Quality Control in Buenos Aires were also considered.

The selection of cities was based on geographic similarities found within this set, the availability of materials for analysis, and the principles of air quality legislation in these locations. PM_{10} was chosen as

an air quality parameter because it is a pollutant that can be tracked through a wide monitoring network, which requires no sophisticated equipment for measurement, and is one of the oldest in place. The procedures used for disclosing official data comply with international methodologies. The period from 2002 to 2018 was the one in which all five cities had data available on their websites at the beginning of this research.

There are many ways to measure PM_{10} worldwide, for example, through the network of air quality stations or satellites. But the best and most detailed way is the local air quality stations, once the main sources are also local, such as automobiles, industries, and biomass burning that can influence the atmosphere regionally. To accomplish this, it is necessary to have a network of stations (Figure 1).

Except for the municipality of Porto Alegre, the departments responsible for monitoring air pollution are at the state level in the Brazilian case, at the departmental level in Uruguay, and autonomous city level in Argentina. Municipal data from Porto Alegre were used to supplement the State air quality report, which has not used municipal station records since 2008.

In possession of these documents from the years 2002 to 2018, when all were available online, a reading was carried out with a specific focus on the points of interest of the study: the environmental legislation that is based on air quality control, the geographical data of the cities, and records of PM_{10} concentration, both for annual average and for the maximum in 24-hour period.

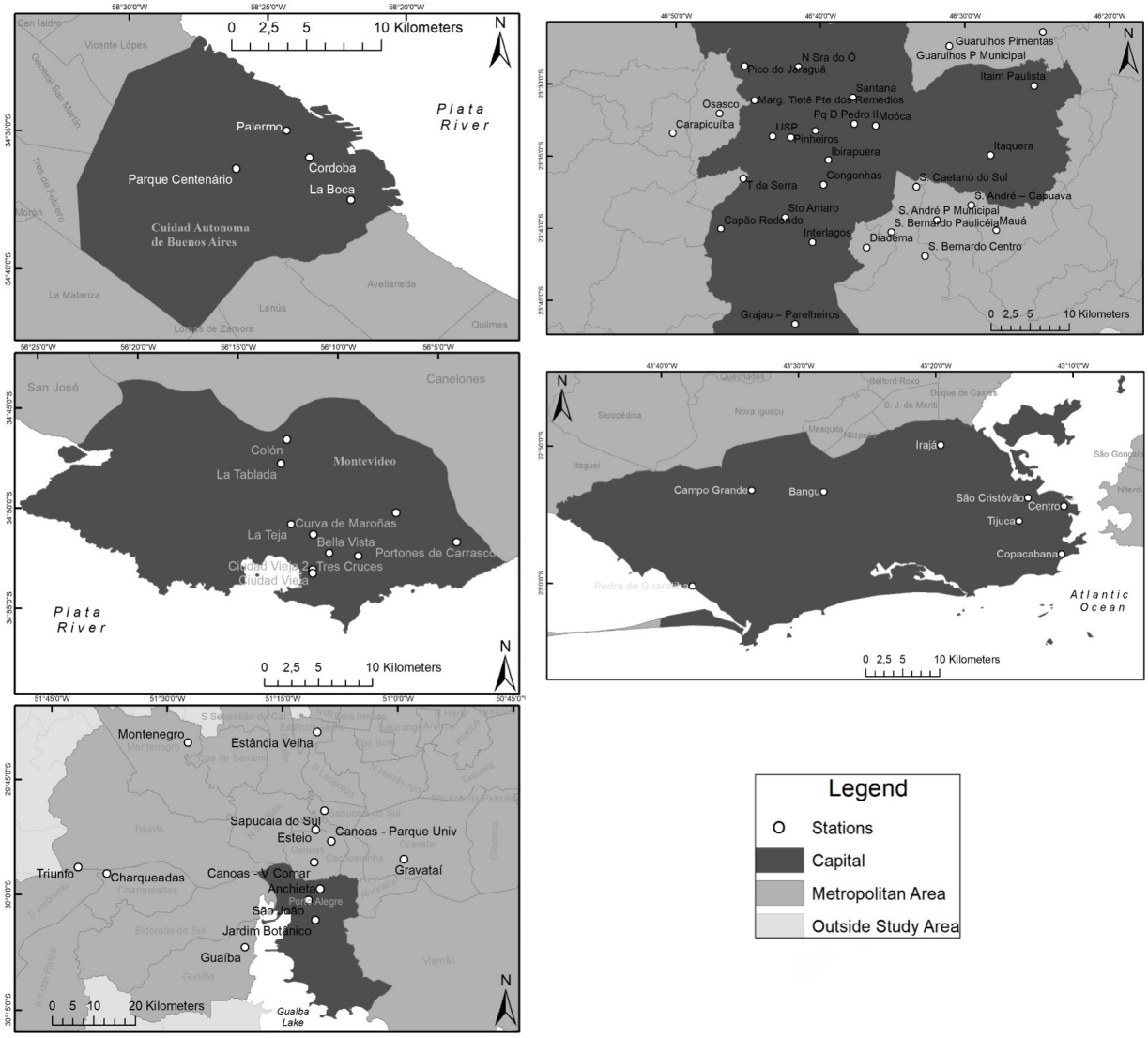

Figure 1 – The five urban centers of the study areas in South America.

In order to establish the comparison between the air quality reports, determined evaluation criteria were considered, including the general format of the reports (newsletters or longer publications) and their publication interval (regular or sporadic). These aspects are crucial for a well-designed air quality report, as it serves as an essential instrument for disclosing the behavior of atmospheric pollution. A comprehensive report should also incorporate temporal evolution, such as considering records from previous years for analysis.

After this analysis, for each document, it was observed whether there was a mention of the legal bases and their depth on these bases, for example, if there was only one citation or a more extended description of the laws, either to explain, propose, or justify the State's actions for controlling air pollution, and, if there were any proposals of public policies through increments in legislation to improve air quality.

The geographic factors of the places studied were also considered important to be included in the reports, thus, characteristics such as geomorphology (relief study) and climatology were mentioned. These two elements of geography directly influence the records of contaminants, serving as facilitators or obstacles in the dispersion of pollutants (Brandão, 1992). Other factors such as urban sprawl can also contribute to air quality data and, if mentioned in the documents, they were also considered (Figure 2).

Figure 2 – South America study area map.

PM_{10} report data revealed the location of each surveyed station, excluding those that were not in the area of interest. Annual average and the maximum in 24 hours of this subset of stations were computed.

The data extracted from the reports were tabulated and graphs were constructed for better visualization and comparison with each other. At the same time, the reports disclosed the allowable limits of PM_{10} in the region and the laws on which they were relying on. So, based on this information, it was possible to calculate the number of overtakes in the year and the tolerance allowed by each agency, both for the annual average and the maximum in 24 hours.

As this is a qualitative research, based on the analysis of published documents, we used no statistical tools. The methodology is summarized in Table 1.

Study area

The five study cities match each other from all perspectives of this research. Although they have different urban areas, the laws could be compared, as well as the activities developed. All of them are capitals, have industrial zones nearby, a large fleet of automobiles, and a green belt on the edge of the metropolitan zone. Some have more air quality stations than others, with variations, which could reflect society's concern about pollution. All stations provide average hourly and daily data. São Paulo had more stations during all the 17 years studied.

Results

General characteristics of air quality reports

The publications in each city were more clearly seen in complete book format, with annual or biennial regularity. It was noticed that the content of the reports of the cities that opted for this format varied over time, in general, when there was a change in authors and technical staff. Although these publications did not leave aside the discussion of the scope of work topics, there were changes in the layout, number of pages, and number of attachments.

São Paulo presented extensive reports, very detailed and with some changes, both in the law, when it implemented its own legislation in 2013, and in the historical analysis of pollution, adopting the moving average for the last three years instead of ten years.

Montevideo presented a report very similar to that of São Paulo and the air quality limits are only State propositions that are followed by society, there is no weight of law. There were no specific laws determining limits for PM_{10}. Textually, the state of São Paulo was a reference for Uruguay in terms of air quality control (Uruguay, 2006). Buenos Aires decided to assemble them in a heterodox format, in monthly bulletins of approximately three pages, taking out of context the other factors to be evaluated. Porto Alegre and Rio de Janeiro did not have regularity in the preparation of documents, which hampered data analysis.

Table 1 – Study methodology.

Area	Product	Source	Goal
Reports	Air Quality Reports from 2002 to 2018	INEA / CETESB / FEPAM / Control de la Calidad Ambiental / Laboratorio de Calidad Ambiental	Air Quality Evolution from 2000 to 2010 decade considering: PM_{10} annual and 24 hours average; Air quality stations (count); PM_{10} Overruns; Cited legislation; Geographic factors; Suggestions to improve air quality.
Geography	Localization Maps	Global Area Administrative / INEA / CETESB / FEPAM / Control de la Calidad Ambiental / IBGE / IGN / Intendencia de Montevideo / Google Maps	Point the study area and air quality stations
Laws	International reports of PM10 limits	UN / WHO / US EPA / CalEPA / European Comission	Worldwide PM_{10} limits to compare with the five urban centers
	Legislation analysis Argentina / Uruguay / Brazil	Presidencia de la Nación / Poder Legislativo / Presidência da República	State responsibilities on collective health and environment

INEA: State Institute of the Environment of Rio de Janeiro (*Instituto Estadual do Ambiente*); CETESB: Environmental Company of State of São Paulo (*Companhia Ambiental do Estado de São Paulo*); FEPAM: State Environmental Protection Foundation Henrique Luis Roessler of Porto Alegre (*Fundação Estadual de Proteção Ambiental Henrique Luis Roessler*); IBGE: Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística)*; IGN: *Instituto Geográfico Nacional de la República Argentina*; um: United Nations; WHO: World Health Organization; US EPA: United States Environmental Protection Agency; CalEPA: California Environmental Protection Agency.

The state of Rio Grande do Sul exhibited a different scenario, as it presented a gap between 2003 and 2012, which was published only in 2014 (FEPAM, 2014). When it was finally published, data from the municipality of Porto Alegre were incomplete and stopped in 2008. Thus, data from the municipal station, managed by the SMAMUS, were used to complete the series.

Rio de Janeiro has presented annual reports since 2007 and biannual reports in 2010–2011 and 2011–2012, but from 2016 it no longer published them, justifying it in its electronic address with the following argument, which remained unchanged or irregular until July 2021:

> IMPORTANT WARNING! Due to the publication of CONAMA Resolution No. 491 of 11/19/2018, which changes national air quality standards and determines a new range for the air quality index, the Air Quality Reports for the years 2016, 2017, and 2018 are under review and will be published in January 2020 (INEA, 2021).

Characterization of air quality limits and legislation

The normative standards were similar between the analyzed cities, which assumed national legislation as the standard in their reports (Table 2). São Paulo was the only city to implement its own legislation on air pollution in 2013. All of them considered US standards (US EPA) in their reports, in addition to WHO recommendations for such pollutants, especially when there were no national standards to be followed, such as what happened with Rio de Janeiro[1], and Montevideo. These cities still did not have regulations for $PM_{2.5}$, but they were already making an effort and monitoring the limits unofficially.

Between 2002 and 2018, São Paulo and Montevideo presented changes in PM_{10} limits. Initially, Uruguay allowed a fluctuation in the daily average between 100 and 150 μg/m³ and in 2016 they adopted 100 μg/m³. The state of São Paulo changed its air quality limits in 2013, reducing PM_{10} levels (Table 2).

Table 2 – Ambient air pollution standards/guide values for PM_{10} (2002–2018).

Particulate Matter Tolerance Legislation		
	PM_{10} (μg/m³)	
	24 hours average	Annual average
Buenos Aires	150	50
Montevideo (until 2016)	100 to 150	50
Montevideo (since 2016)	100	50
Porto Alegre	150	50
São Paulo (until 2012)	150	50
São Paulo (since 2013)	120	40
Rio de Janeiro	150	50
Guide Values and Recommendations		
US EPA	150	-------
WHO (since 2015)	50	20

[1] CONAMA Resolution 491/2018 began to contemplate the measurement of PM2.5 nationally, however, Rio de Janeiro did not make the reports available for that year.

Brazil established its air quality standards with CONAMA Resolution 003/1990 of August 1990 (Brazil, 1990). It was updated in 2018 with the new Resolution 491/2018 of November 2018, 28 years later, but was not considered (Brazil, 2018) in the study for having entered into effect only at the end of the year, and the report with the new standards would be published after the time period of the study. São Paulo adopted the same legislation as in 1990 and updated it in April 2013 (São Paulo, 2013). Rio de Janeiro and Porto Alegre followed the national rule. Buenos Aires nationalized the US EPA standards in 2004 (Buenos Aires Ciudad Autonoma, 2004). Before that, the country had the same rules as the US EPA, but with the limits of April 1973, according to national law 20.284/73 (Argentina, 1973), that is, updated 31 years later.

Unlike the other places surveyed, Uruguay does not have a national decree for air quality control, however, it follows proposals from the competent bodies. The Municipal Administration (*Intendencia Municipal de Montevideo*) organized its rules in June 1993 with the Mechanical and Electrical Service (*Servicio de Instalaciones Mecánicas y Eléctricas*) (Uruguay, 2006), updating it according to DINAMA (*Dirección Nacional de Medio Ambiente*) in 2016, therefore valid for 23 years. It is pointed out that, in the last review, Montevideo mentioned São Paulo legislation as an international parameter to follow.

The cities that used environmental legislation the most as a framework for constructing air quality reports were Rio de Janeiro, São Paulo, Porto Alegre, and Montevideo. In their reports, it was observed that the laws were explained in order to contextualize and give meaning to the existence of those rules and their purpose, in this case, the improvement of air quality. The authorities that proposed new legislation in their air quality reports were Rio de Janeiro, São Paulo, and Montevideo. They did so in different ways, such as preparing schedules of actions to improve air quality, future perspectives on atmospheric pollution, suggestions for State actions, or publicizing government programs and projects in the area. Buenos Aires only mentioned in its bulletins the law on which it was based, and that spurred the elaboration of its document — Law 1.356/04.

Geographic factors in air quality reports

The same cities that most mentioned the legislation were those dedicated to contextualizing geographic factors regarding PM_{10} concentration. All addressed both relief — geomorphology and climatology — in extensively illustrated descriptions, and relationships of these factors with air quality. On the contrary, Buenos Aires was the only city that did not consider any of these aspects.

São Paulo divided its air quality report so that the state was subdivided based on watersheds — the Water Resources Management Units (UGRHI). This division makes sense when we consider the concepts of air basin in which the particles in suspension can carry pollutants suspended in the atmosphere to water bodies through precipitation and, in extreme cases, impair water quality and the local ecosystem (CETESB, 2009). But this organization was gradually abandoned, and from 2014, it was organized according to pollutants (CETESB, 2015). Thus, each contaminant was featured in a chapter, and its behavior was described for each air quality station, following the political divisions of the state — Metropolitan Region, Interior, and Baixada Santista.

This adaptation in classifying the air quality stations in São Paulo facilitated the comparison between states because it improved the location of the cities under study and equaled the other cities. Rio de Janeiro, Porto Alegre, and Montevideo were already preparing their documents for the political division.

The report from the Uruguayan capital also considered the activities around the air quality stations, e.g., if there was any industry or large avenues nearby. This analysis facilitates the prognosis of the behavior of these records and may even be part of the explanation for some cases of pollution limits violation, especially when associated with climatology and geomorphology (Intendencia de Montevideo, 2018).

Porto Alegre and Rio de Janeiro sought explanations for air quality violations in geographic factors. The first even raised meteorological satellite images to point out the exceptionality of the fact, as in 2013 (FEPAM, 2014). The second city attributed air quality violations to state urban infrastructure works for the preparation of the Olympic Games and the Soccer World Cup to explain the violation in the annual average of PM_{10} in different seasons and for a long time (INEA, 2015).

Porto Alegre and Montevideo are notified of extreme or exceptional events (such as volcanism) in their reports. Such events, in addition to causing inconvenience, also cause the worsening of air quality even over long distances and indefinitely time.

PM_{10} records

The air quality records, in general, have shown a decline and stabilization since 2015 (Figure 3) in the study cities. Problems in data collection were reported, mainly in Rio de Janeiro, Porto Alegre, and Buenos Aires and occasionally in other cities, resulting in some gaps in the data series.

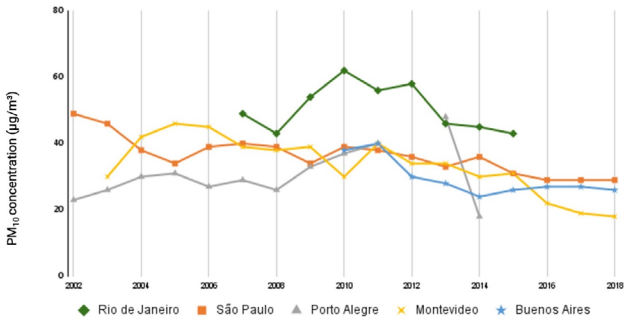

Figure 3 – Annual PM_{10} average concentration (µg/m³) from 2002 to 2018.

Based on the historical series of PM_{10}, Montevideo has continuously shown the best air quality among the five cities since 2002, in constant fall since 2016, and in 2019 presented the best air quality, with the lowest annual average and the lowest maximum in 24 hours. On the contrary, Rio de Janeiro had a short series and poor air quality compared to the others, even though there has been a downward trend since 2013 (Figure 3).

The PM_{10} report results showed that Rio de Janeiro was the only city to exceed the limit of the annual average (50 μg/m³), which occurred between 2009 and 2013. The others, in the latest records, were up to 42% below the annual average legislation (Figure 3). Montevideo registered just 18 μg/m³, the only city to comply with all recommendations, including the WHO, which is the strictest (Table 2) and was updated again in 2021.

Of the 17 years surveyed (2002–2018), the records of maximum in 24 hours in Rio de Janeiro exceeded in all but five years (2012, 2013, 2015, 2016, and 2017). There is a tolerance of one exceeding per year, but sometimes even this rate was exceeded (Figure 4).

One of the ways to check the accuracy of air pollution data is the number of air quality stations that were in service during the sampling time. Some stations were closed for maintenance or sometimes due to lack of funds. In general, the more stations available, the more accurate the measurement will be, so the number of equipment available over time was also monitored (Figure 5).

The cities of Porto Alegre and Buenos Aires remained practically stable. However, it is expected that after 17 years of study and with the phenomenon of urban expansion, the network should be increased to improve data quality (Figure 6).

Discussion

Observing the city reports, according to the publication design, the cities that presented data in book format were able to better explore the subjects and address other points to corroborate the results measured during the year or justify any violations of the established limits.

One problem identified was the lack of regular disclosure of reports, either annually, which would be the ideal frequency, or biannually. Regularity helps monitor the evolution of pollution levels and allows for the identification of the effects of public air quality policies or isolated meteorological events at an early stage.

During the analysis, it was noticed a lack of integration of the stations data in Porto Alegre from 2008 onwards. Using the results from the municipal stations hinders the reliable calculation of air quality in Rio Grande do Sul and interferes with the assessment of the State's situation.

Rio de Janeiro delayed the publication of reports since 2016 and promised to deliver them in 2020. However, this has not yet been accomplished. It is a fact that the pollution limits changed in Brazil, in 2018, but too much time has passed to update these numbers.

As previously mentioned, the type of publication in book format proved to be better due to the space in which the authors had to propose solutions or mitigating actions for atmospheric pollution. Since there is a technical staff specialized in preparing the document, it is expected that the group's suggestions will also be relevant, thus, this technical opinion enriches the debate on the subject in society.

Opting for a monthly bulletin format confer Buenos Aires the advantage of checking pollutants on a shorter time scale. On the other hand, it loses in contextualizing the facts since any pollution peaks could be accompanied by some technical explanation.

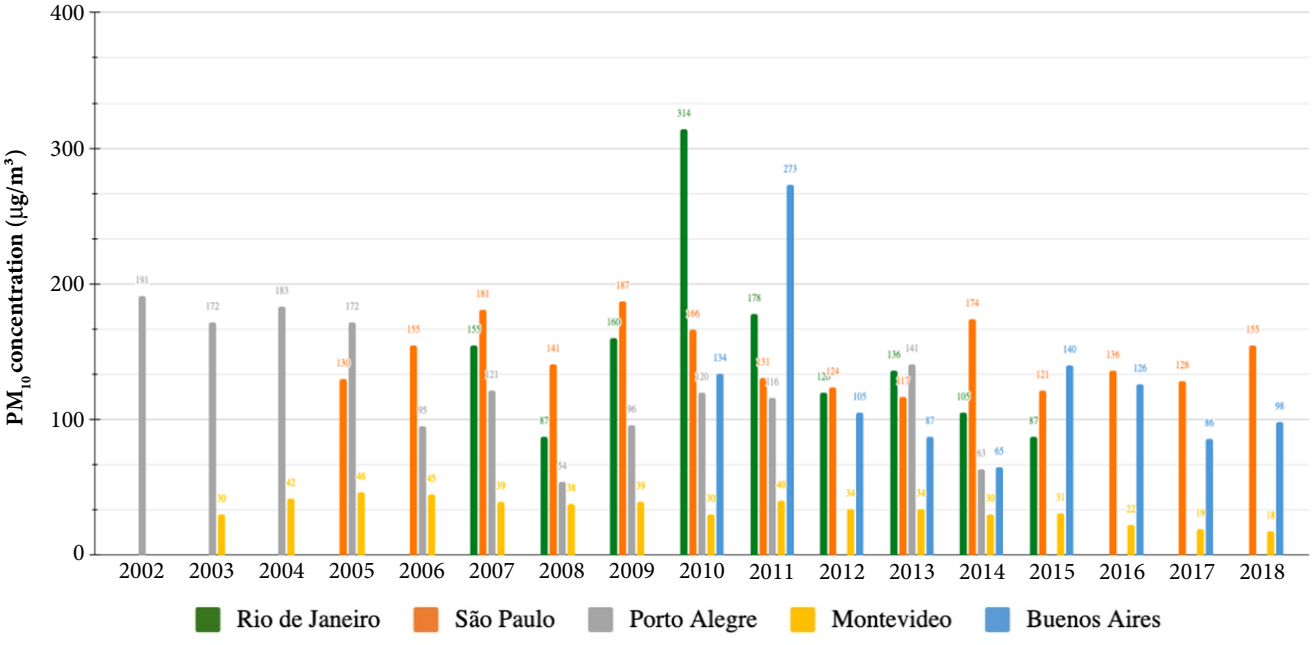

Figure 4 – Maximum PM_{10} concentration (μg/m³) in 24 hours from 2002 to 2018.

The lack of this technical support impairs the reading of the dynamics of air pollution in the city.

The analysis of the PM_{10} samples revealed that the air quality in Rio de Janeiro is worse than the others, registering even exceeded limits on several occasions, which demonstrates that the rules in Brazil are less rigorous (150 µg/m³) than in Uruguay, for example.

Cities of different sizes such as São Paulo (the largest in South America) and Buenos Aires ended the last three years with concentrations of PM_{10} very similar to each other, even with the problems of Buenos Aires in terms of number of stations and their distribution, that would tend to measure less pollution. This means that, despite the size discrepancy, similar concentrations of PM_{10} demonstrate that smaller cities can pollute a lot.

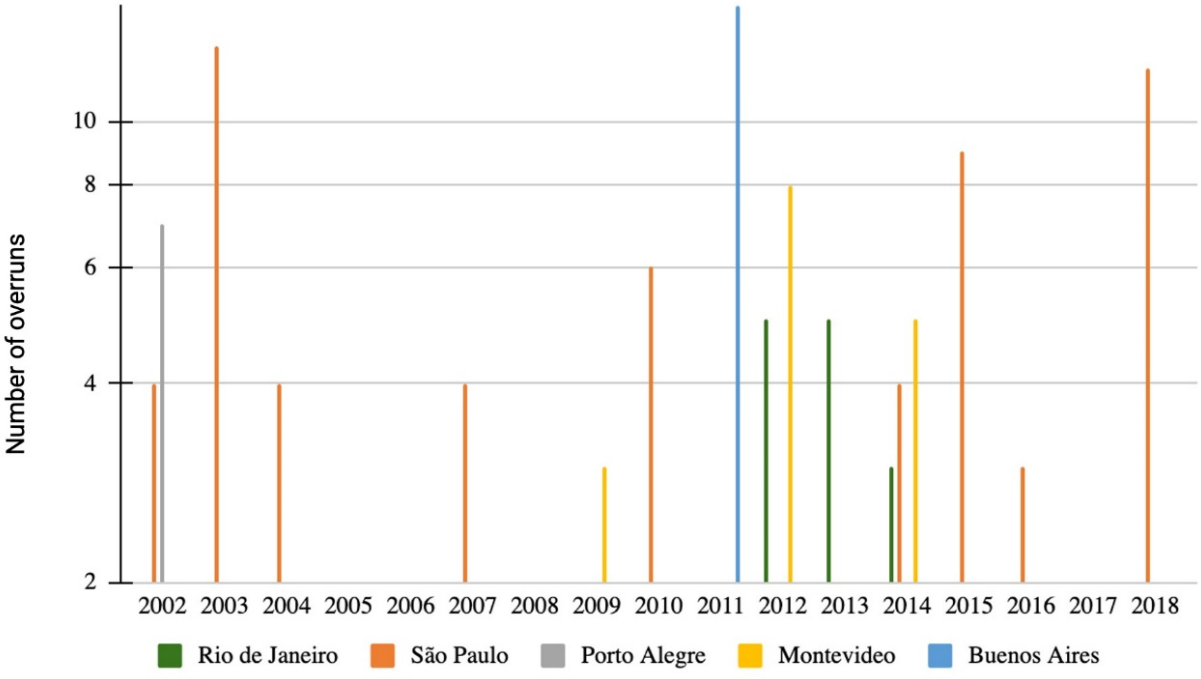

Figure 5 – Number of overruns of the maximum 24 hours PM_{10} concentration.

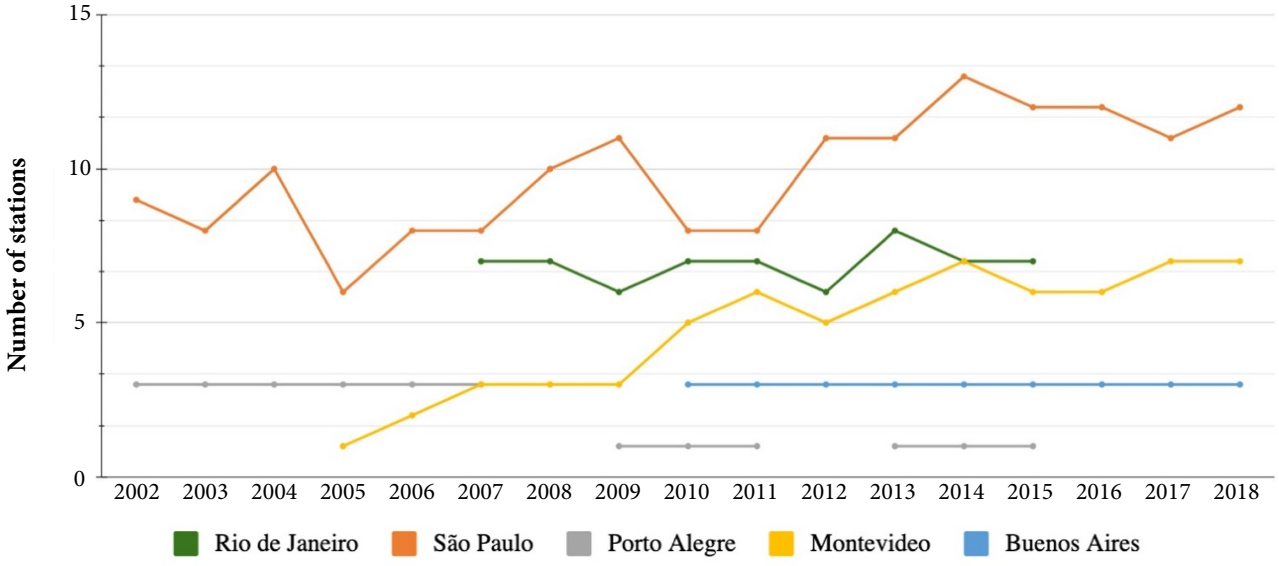

Figure 6 – Evolution in the number of stations from 2002 to 2018.

Cities of similar size and relief, such as Buenos Aires, Porto Alegre, and Montevideo, behaved differently. Porto Alegre proved to be less polluted than the Uruguay and Argentina capitals for many years. Montevideo and Buenos Aires had similar evolutionary curves, often less polluted. However, since 2016, Montevideo has shown a decrease in PM_{10}, coincidentally following an overhaul of emissions rules (Uruguay, 2013). Despite the apparent effect of the new rules in Uruguay, geographic factors in addition to terrain and urban area may also have weighed in on this comparison. It should be noted that São Paulo was another city to undergo air quality rules reformulation in the period, in 2013 (CETESB, 2014), and also presented the same behavior as Montevideo, with a slight decrease from 2014. For more assertive results, more time is still needed for monitoring.

In the analysis of the records, a drop in air quality was noted in the driest months in all cities. Those with flatter relief, such as Buenos Aires and Montevideo, despite the worsening in the dry months, showed less PM_{10} deterioration. These associated factors were pointed out in the reports and it was reinforced the importance of a multidisciplinary approach to the issue of pollution and the implications of the most diverse orders.

As for the number of air quality stations, Porto Alegre and Buenos Aires should perhaps consider expanding their monitoring network since they have maintained the same stations despite the trend toward urban expansion.

Geographical factors were considered by the authors of the reports in all cities and all years, except Buenos Aires. Geography sub-areas such as climate, geomorphology, and urbanization were addressed in most documents in virtually all years of study. However, the urban expansion of the city was not considered, which should be an important indicator to highlight possible locations for the installation of new monitoring stations. In another study on an average city, Pinheiro et al. (2020) concluded that winds and precipitation, in addition to the size of the input source, were determinants for the worsening of air quality, which corroborate the conclusions of the present study.

The location of air quality stations is mixed, with some near downtown, some in green areas, and others in industrial parks. However, Buenos Aires placed them near green or residential areas, meaning that in the long term, the city will not measure pollution from industries.

One data was not verified in the reports: the area of influence of the air quality stations. This is a subject that must be included in future studies with the aim of measuring the coverage of air quality in cities. The association of this coverage with the urban climate should also be present and, with a larger sample of air quality stations, replicate the methodology for fine particulate matter ($PM_{2.5}$), which unfortunately still has few monitoring points among the areas studied. On the other hand, performing atmospheric modeling to estimate the $PM_{2.5}$ in the places of interest, as pointed out by Godoy et al. (2021), can be an intermediate solution.

This study theme has high complexity due to its multifactorial nature. It is also known that poor countries have difficulties measuring, maintaining, and expanding the air quality stations network. Perhaps international funding should be considered to address pollution problems, promote environmentally friendly practices, and pressure politicians to enact laws that align with WHO recommendations.

Conclusion

The theme of this study is highly complex, due to its multifactorial nature. Trying to link the different areas of knowledge around the problem of atmospheric contamination required deepening specific concepts from areas such as law and collective health. Associated with the environmental issue, there is a continuous effort by the states to control pollution limits, with direct impacts on the population's health, and the obstacles that arise in the implementation of actions to mitigate emissions, such as the high costs of monitoring equipment, or new filters for factories and engines that emit fewer pollutants.

Taking the analysis of the air pollution report as a reference, specifically regarding PM_{10}, it is concluded that the surveyed cities had limitations in preparing their air quality reports.

Among the five cities studied, São Paulo presented the most complete reports. The others followed the presentation of data as São Paulo but still need to improve in the depth of the analyses since the interconnection between the survey of PM_{10} data, their justifications when they exceed the limits, and consequences are not very clear in the documents.

Regarding compliance with PM_{10} concentration limits, Rio de Janeiro was unable to remain within the tolerated parameters. The others, despite occasional exceedances, managed to do so and tried to justify the atypical events in the reports. Unfortunately, the parameters followed by Buenos Aires, Montevideo, Rio de Janeiro, and Porto Alegre are still quite tolerant compared to the European and US limits and much more flexible than those recommended by the WHO.

The lack of reasonable air quality coverage for some cities, as well as the expansion of $PM_{2.5}$ and $PM_{0.1}$, called ultrafine particles, makes some cities more distant in adapting to the UN Millennium Goals (ONU, 2000), jeopardizing sustainability and compromising the environment for future generations.

Contribution of authors:

SILVEIRA, T. S.: conceptualization; data curation; methodology; writing — original draft; writing — review & editing. SANTOS, R. R.: visualization; writing — review & editing. AITH, F. M. A.: writing — review & editing. GOUVEIA, N.: funding; supervision.

References

Argentina, 1973. Ley 20.284/73. Plan de prevención de situaciones críticas de contaminación atmosféricas (Accessed July 12, 2018) at:. http://servicios.infoleg.gob.ar/infolegInternet/anexos/40000-44999/40167/norma.htm.

Brandão, A.M.P.M., 1992. As alterações climáticas na área metropolitana do Rio de Janeiro. In: Abreu, M.A. (Ed.), Natureza e sociedade no Rio de Janeiro. Secretaria Municipal de Cultura, Turismo e Esporte, Rio de Janeiro.

Brasil, 1990. Resolução do Conselho Nacional do Meio Ambiente (Accessed June 15, 2009) at:. http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=100.

Brasil, 2018. Resolução nº 491/2018. Padrões de Qualidade do Ar (Accessed February 10, 2020) at:. http://www.in.gov.br/web/guest/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/51058895/do1-2018-11-21-resolucao-n-491-de-19-de-novembro-de-2018-51058603.

Buenos Aires Ciudad Autonoma, 2004. Ley 1356/04. Regula la preservación del recurso del aire. (Accessed July 16, 2018) at: https://www.argentina.gob.ar/normativa/provincial/ley-1356-123456789-0abc-defg-653-1000xvorpyel/actualizacion.

Companhia Ambiental do Estado do São Paulo (CETESB), 2009. Relatório de qualidade do ar no estado de São Paulo 2008. CETESB, São Paulo (Accessed November 9, 2017) at: https://cetesb.sp.gov.br/ar/publicacoes-relatorios/.

Companhia Ambiental do Estado do São Paulo (CETESB), 2014. Qualidade do ar no estado de São Paulo 2013. CETESB, São Paulo (Accessed November 12, 2011) at: https://cetesb.sp.gov.br/ar/publicacoes-relatorios/.

Companhia Ambiental do Estado do São Paulo (CETESB), 2015. Qualidade do ar no estado de São Paulo 2014. CETESB, São Paulo (Accessed November 2017, 11) at:. http://www.cetesb.sp.gov.br/ar/qualidade-do-ar/31-publicacoes-e-relatorios.

Corá, B.; Leirião, L.F.L.; El Khouri Miraglia, S.G., 2020. Impacto da Poluição do Ar na Saúde Pública em Municípios com Elevada Industrialização no Estado de São Paulo. Brazilian Journal of Environmental Sciences, v. 55, (4), 498-509. https://doi.org/10.5327/Z2176-947820200671.

Fundação Estadual de Proteção Ambiental Henrique Luis Roessler (FEPAM), 2014. Diagnóstico da Qualidade do Ar no Rio Grande do Sul no Período de 2003 a 2012. FEPAM, Porto Alegre (Accessed November 23, 2016) at:. http://www.fepam.rs.gov.br/.

Godoy, A.R.L.; Silva, A.E.A.; Bueno, M.C.; Pozza, S.A.; Coelho, G.P., 2021. Application of machine learning algorithms to PM2.5 concentration analysis in the state of São Paulo, Brazil. Brazilian Journal of Environmental Sciences, v. 56, (1), 152-165. https://doi.org/10.5327/Z21769478782.

Gouveia, N., 1999. Saúde e Meio Ambiente nas Cidades: os desafios da saúde ambiental. Saúde e Sociedade, v. 8, (1), 49-61. https://doi.org/10.1590/S0104-12901999000100005 .

Hamra, G.B.; Guha, N.; Cohen, A.; Laden, F.; Raaschou-Nielsen, O.; Samet, J.M. P.; Vineis, P.; Forastiere, F.; Saldiva, P.; Yorifuji, T.; Loomis, D., 2014. Outdoor particulate matter exposure and lung cancer: a systematic review and meta-analysis. Environmental Health Perspectives, v. 122, (9), 906-911. https://doi.org/10.1289/ehp/1408092.

Instituto Estadual do Ambiente (INEA), 2015. Relatório de Qualidade do Ar do Estado do Rio de Janeiro - 2015. INEA, Rio de Janeiro (Accessed October 20, 2020) at:. http://www.inea.rj.gov.br/wp-content/uploads/2019/01/RQAr_2015.pdf.

Instituto Estadual do Ambiente (INEA), 2021. Relatório de Qualidade do Ar. INEA, Rio de Janeiro (Accessed July 14, 2021) at:: http://www.inea.rj.gov.br/ar-water-and-soil/air-quality-monitoring-andmeteorology/.

Intendencia de Montevideo, 2018. Principales contaminantes del aire. Montevideo, Intendencia de Montevideo (Accessed September 2, 2018) at:. https://montevideo.gub.uy/sites/default/files/biblioteca/informe2018.pdf.

Mercosul, 2001. Acordo-Quadro Sobre Meio Ambiente do Mercosul. Mercosul, Assunção.

Minayo, M.C., 2014. O Desafio de Conhecimento. 14ª. Hucitec, São Paulo.

Newell, K.; Kartsonaki, C.; Lam, K.B.H.; Kurmi, O.P., 2017. Cardiorespiratory health effects of particulate ambient air pollution exposure in low-income and middle-income countries: a systematic review and meta-analysis. The Lancet Planetary Health, v. 1, (9), e368-e380. https://doi.org/10.1016/s2542-5196(17)30166-3.

Nogarotto, D.C.; Canteras, F.B.; Pozza, S.A. 2022. Brazilian truckers' strike and particulate matter (PM10) concentration: Temporal trend and time series models. Brazilian Journal of Environmental Sciences, v. 57, (3), 477-490. https://doi.org/10.5327/Z2176-94781386.

Organização das Nações Unidas (ONU), 2000. Objetivos de Desenvolvimento Sustentável. ONU (Accessed April 3, 2021) at:. https://brasil.un.org/pt-br/sdgs.

Organização Mundial da Saúde (WHO), 2018. World Health Organization. (Accessed March 14, 2009) at:. http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

Organização Mundial da Saúde (WHO); Organização Pan-Americana da Saúde (PAHO), 2018. La Nueva Base de Datos de Calidad del Aire y Salud de la OMS. OPAS / OMS, Genebra (Accessed June 6, 2019) at:. https://www.paho.org/hq/index.php?option=com_docman&view=download&category_slug=presentaciones-9912&alias=45394-la-nueva-base-datos-calidad-aire-salud-oms-2018-394&Itemid=270&lang=pt.

Park, C.C., 1987. Acid Rain Rhetoric and Reality. Methuen & Co., London.

Pinheiro, J., Venturi, L.A.B., Galvani, E., 2020. Poluição atmosférica: estudo de caso do Município de São Luís do Maranhão. Sociedade e Natureza, v. 32, 808-819. https://doi.org/10.14393/SN-v32-2020-56162.

São Paulo, 2013. Decreto 59.113/13. Estabelece novos padrões de qualidade do ar e dá providências correlatas (Accessed July 17, 2018) at:. https://www.al.sp.gov.br/repositorio/legislacao/decreto/2013/decreto-59113-23.04.2013.html.

Silva, M.D.; Oliveira, M.C.Q.D.; Drumond, A.; Rizzo L.V., 2021. Air pollutants associated with surface meteorological conditions in São Paulo's ABC region. Brazilian Journal of Environmental Sciences, v. 56, (3), 459-469. https://doi.org/10.5327/Z21769478917.

Souza, L.R., Hartmann, D.; Silveira, T.A., 2015. Dano Ambiental e a Necessidade de uma Atuação Proativa da Administração Pública. Veredas do Direito, v. 12, (24), 343-373. https://doi.org/10.18623/rvd.v12i24.630.

Uruguay, 2006. Informe Anual de la Red de Monitoreo de Calidad del Aire de la Ciudad de Montevideo. Servicio Laboratorio De Calidad Ambiental, Departamento de Desarrollo Ambiental, Montevideo, 88 pp.

Uruguay, 2013. Decreto 152/013. Ley general del medio ambiente. (Accessed July 16, 2018) at:. https://www.impo.com.uy/bases/decretos/152-2013.

World of Health Organization (WHO), 2022. Global Air Quality Guideliness (Accessed April 3, 2023) at:. https://www.who.int/publications/i/item/9789240034228.